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## SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Kazutaka Hanaoka, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Yuichi Inoue, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Seiji Tanuma, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan and Makoto Ohashi, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan have invented certain new and useful improvements in

## DRIVING OF A LIQUID CRYSTAL DISPLAY DEVICE

of which the following is a specification : -

1 TITLE OF THE INVENTION

DRIVING OF A LIQUID CRYSTAL DISPLAY DEVICE

BACKGROUND OF THE INVENTION

5 The present invention generally relates to liquid crystal display devices and more particularly to the driving of an active-matrix liquid crystal display device in which representation of images is achieved by applying a driving voltage to a liquid  
10 crystal layer via a thin-film transistor (TFT).

Liquid crystal display devices have various advantageous features such as compact size, light weight, low power consumption, and the like. Thus, liquid crystal display devices are used extensively in  
15 portable information processing apparatuses such as lap-top computers or palm-top computers. Further, liquid crystal display devices are used also in desk-top computers in these days.

A typical liquid crystal display device  
20 includes a liquid crystal layer confined between a pair of glass substrates and achieves representation of images by inducing a change in the orientation of liquid crystal molecules in the liquid crystal layer by applying a driving voltage to the liquid crystal  
25 layer. Such a change in the orientation of the liquid crystal molecules causes a change in the optical property of the liquid crystal layer.

In the case of using such a liquid crystal display device in a high-resolution color  
30 representation apparatus, there is a need of driving the individual pixels or liquid crystal cells defined in the liquid crystal layer at a high speed. In order to meet this requirement, it is generally practiced to provide a thin-film transistor in correspondence to  
35 each of the pixels in the liquid crystal layer and to drive the liquid crystal cells by way of such thin-film transistors.

1           FIG.1 shows the construction of a liquid  
crystal panel 10 used in such an active matrix liquid  
crystal display device of a related art in a plan  
view, while FIG.2 shows the part circled in FIG.1 in a  
5           cross-sectional view.

Referring to FIG.2, the liquid crystal panel  
10 generally includes a pair of glass substrates 10A  
and 10B, and a liquid crystal layer 10C is confined  
between the substrates 10A and 10B.

10           As represented in the plan view of FIG.1,  
the glass substrate 10A carries thereon a number of  
thin-film transistors  $11_1 - 11_4$  corresponding to the  
pixels in a row and column formation, wherein the  
thin-film transistors  $11_1$  and  $11_2$  aligned in the row  
15           direction are connected commonly to a gate bus line  $G_1$   
provided directly on the glass substrate 10A.  
Similarly, the thin-film transistors  $11_3$  and  $11_4$  are  
connected commonly to a gate bus line  $G_2$  provided  
directly on the glass substrate 10A. Further, the  
20           glass substrate 10A carries thereon a number of  
generally H-shaped auxiliary electrodes Cs at the  
level of the gate bus lines  $G_1$  and  $G_2$ , wherein the  
auxiliary electrode Cs is covered by an insulation  
film 12 as represented in the cross-sectional view of  
25           FIG.2, and data bus lines  $D_1$  and  $D_2$  are formed on the  
insulation film 12 so as to extend in the column  
direction as represented in the plan view of FIG.1.

It should be noted that the data bus lines  
 $D_1$  and  $D_2$  are covered by another insulation film 13 as  
30           represented in the cross-sectional view of FIG.2, and  
the data bus line  $D_1$  is connected to the respective  
source regions of the thin-film transistors  $11_1$  and  
 $11_2$  via a conductor pattern branched from the data bus  
line  $D_1$ . Similarly, the data bus line  $D_2$  is connected  
35           to the respective source regions of the thin-film  
transistors  $11_2$  and  $11_4$  via a conductor pattern  
branched from the data bus line  $D_2$ .

1 Further, there is provided a rectangular  
pixel electrode of a transparent conductor such as ITO  
on the insulation film 13 in correspondence to the  
drain region of each of the thin-film transistors.  
5 For example, the drain region of the thin-film  
transistor 11<sub>1</sub> is connected to a transparent pixel  
electrode P<sub>1</sub> provided on the insulation film 13 via a  
contact hole formed in the insulation film 13. As can  
be seen from FIGS.1 and 2, the auxiliary electrode Cs  
10 is disposed at both sides of the data bus line D<sub>1</sub> or  
D<sub>2</sub> when viewed in the direction perpendicular to the  
substrate 10A, such that the electrode Cs overlaps the  
edge part of the transparent pixel electrode P<sub>1</sub> or P<sub>2</sub>.  
Thereby, the auxiliary electrode Cs forms an auxiliary  
15 capacitor together with the transparent pixel  
electrode P<sub>1</sub> or P<sub>2</sub>.

Further, each of the transparent pixel  
electrodes P<sub>1</sub> and P<sub>2</sub> is covered by a molecular  
alignment film 14, wherein the molecular alignment  
20 film 14, contacting directly with the liquid crystal  
layer 10C, induces an alignment of the liquid crystal  
molecules in the liquid crystal layer 10C in a  
predetermined direction.

The opposing substrate 10B, on the other  
25 hand, carries a color filter CF in correspondence to  
the foregoing transparent pixel electrode P<sub>1</sub> or P<sub>2</sub>,  
and a transparent opposing electrode 15 of ITO, and  
the like, is provided uniformly on the substrate 10B.  
It should be noted that the transparent opposing  
30 electrode 15 is covered by another molecular alignment  
film 16, and the molecular alignment film 16 induces  
an alignment of the liquid crystal molecules in the  
liquid crystal layer 10C in a desired direction.  
Further, the substrate 10B carries thereon an opaque  
35 mask BM in correspondence to a gap between a color  
filter CF and an adjacent color filter CF.

FIG.3 shows an example of the driving signal

1 supplied to the data bus line  $D_1$  or  $D_2$  when driving  
the liquid crystal panel 10 of FIGS.1 and 2.

Referring to FIG.3, a bipolar driving pulse  
signal is supplied to the data bus line from a driving  
5 circuit, wherein it should be noted that the bipolar  
driving pulse signal changes a polarity thereof  
between a positive peak level of  $+V_D$  and a negative  
peak level  $-V_D$  during the black mode of the liquid  
crystal panel 10 for representing a black image.

10 Further, a predetermined common voltage  $V_{CS}$  is  
supplied to the opposing electrode 15 and the  
auxiliary electrode Cs from another D.C. voltage  
source during the black mode. In the white mode of  
the liquid crystal panel 10 for representing a white  
15 image, on the other hand, on the other hand, a bipolar  
drive pulse signal having an amplitude smaller than a  
predetermined threshold voltage is supplied to the  
foregoing data bus line  $D_1$  or  $D_2$ .

It should be noted that the foregoing D.C.  
20 voltage source for supplying the common voltage  $V_{CS}$  is  
provided as an independent unit independent from the  
driving circuit used for driving the data bus line  $D_1$   
or  $D_2$ . The D.C. voltage source provides a voltage of  
 $\Delta V_c$  as the foregoing common voltage  $V_{CS}$ , wherein the  
25 common voltage  $V_{CS}$  thus set is slightly offset from  
the central voltage  $V_c$  of the bipolar driving pulse  
signal. It should be noted that the liquid crystal  
panel 10 of FIG.1 or 2 uses a low voltage liquid  
crystal, characterized by the black mode drive voltage  
30  $V_D$  of about 5 V or less, for the liquid crystal layer  
10C.

In the liquid crystal panel 10 driven as  
such, it should be noted that the optimum common  
voltage  $V_{CS}$  changes slightly between the black  
35 representation mode and the white representation mode.  
More specifically, the optimum common voltage  $V_{CS}$   
coincides substantially with the central voltage  $V_c$  of

1 the bipolar driving pulse signal ( $\Delta V_c = 0$ ) in the  
black representation mode, while the optimum common  
voltage deviates from the central voltage  $V_c$  ( $\Delta V_c \neq 0$ )  
in the half-tone or white representation mode. As the  
5 common voltage  $V_{Cs}$  is applied uniformly to the  
opposing electrode 15, it is difficult to change the  
common voltage adaptively depending on the content of  
the image to be represented. Thus, it has been  
practiced to fix the common voltage  $V_{Cs}$  to the optimum  
10 voltage at the time of the half-tone representation  
mode.

Meanwhile, the inventor of the present  
invention has noticed, in a liquid crystal panel using  
a low voltage liquid crystal for the liquid crystal  
15 layer 10C, that there appears a noticeable flicker in  
the represented images along the edge part of the  
auxiliary electrode  $C_s$ . In the investigation that  
constitutes the foundation of the present invention,  
the inventor has studied this phenomenon and  
20 discovered that the flicker is caused as a result of  
variation of the disclination which is induced in the  
liquid crystal layer 10C in the region including the  
data bus line  $D_1$  or  $D_2$  and the auxiliary electrode  $C_s$   
by a strong lateral electric field.

25 FIGS.4A and 4B show the alignment of the  
liquid crystal molecules in the liquid crystal layer  
10C and the electric flux of the lateral electric  
field applied to the liquid crystal layer for the case  
in which the common voltage  $V_{Cs}$  applied to the  
30 auxiliary electrode  $C_s$  and the opposing electrode 15  
is offset from the central voltage of the bipolar  
driving pulse signal ( $V_{Cs} \neq V_c$ , wherein FIG.4A shows  
the state in which a voltage of +5V is applied to the  
data bus line  $D_1$  or  $D_2$  (represented as "D"), while  
35 FIG.4B shows the state in which a voltage of -5V is  
applied to the data bus line D.

Referring to FIG.4A, it can be seen that a

1 very large lateral electric field is created between  
the data bus line D and the adjacent auxiliary  
electrode Cs in the state the voltage of +5V is  
5 applied to the data bus line D. Associated with this,  
there occurs a conspicuous disturbance in the  
molecular orientation or disclination in the liquid  
crystal layer 10C in correspondence to the part  
between the data bus line D and the auxiliary  
electrode Cs. As a result of the formation of such a  
10 disclination, there is induced a domain structure in  
the liquid crystal layer 10C, and a leakage of light  
occurs in correspondence to the boundary of the  
domains as represented in FIG.4A by arrows.

In the state of FIG.4B in which a voltage of  
15 -5V is applied to the data bus line D, on the other  
hand, the lateral electric field applied to the liquid  
crystal layer 10C is substantially reduced and there  
occurs no substantial formation of domain structure or  
associated problem of leakage of the light. As the  
20 state of FIG.4A and FIG.4B appears alternately in  
correspondence to the polarity of the bipolar driving  
signal pulse, the leakage light appearing only in the  
state of FIG.4A causes the flicker.

Further, the inventor of the present  
25 invention has discovered that there occurs a flow of  
the liquid molecules in the liquid crystal layer 10C  
in the rubbing direction of the molecular alignment  
film when the value of the common voltage  $V_{CS}$  of the  
auxiliary electrode Cs is deviated from the central  
30 voltage of the bipolar driving pulse signal. When  
such a flow occurs in the liquid crystal layer 10C,  
there occurs an increase in the thickness of the  
liquid crystal layer 10C in correspondence to the part  
where the liquid crystal molecules are accumulated.  
35 When there occurs such a change in the thickness of  
the liquid crystal layer 10C, the optical property of  
the liquid crystal panel 10 is modulated also.

1           Further, in the case a low-voltage liquid  
crystal is used for the liquid crystal layer 10C,  
there tends to occur a sticking of images as a result  
of the accumulation of impurity ions associated with  
5   the flow of the liquid crystal molecules. It should  
be noted that such a low-voltage liquid crystal,  
characterized by a low driving voltage, is  
particularly vulnerable to contamination.

10   SUMMARY OF THE INVENTION

          Accordingly, it is a general object of the  
present invention to provide a novel and useful  
driving method of a liquid crystal display device  
wherein the foregoing problems are eliminated.

15           Another and more specific object of the  
present invention is to provide a method of driving a  
liquid crystal display device, said liquid crystal  
display device comprising: a first substrate; a second  
substrate opposing said first substrate with a gap  
20   therebetween; a liquid crystal layer confined in said  
gap; a thin-film transistor formed on said first  
substrate; a conductor pattern formed on said first  
substrate in electrical connection with said thin-film  
transistor, said conductor pattern supplying an  
25   alternate-current driving voltage signal to said thin-  
film transistor; a pixel electrode provided on said  
first substrate in electrical connection to said thin-  
film transistor; an auxiliary electrode formed on said  
first substrate in the vicinity of said conductor  
30   pattern so as to form an auxiliary capacitance with  
said pixel electrode, said auxiliary electrode being  
disposed so as to induce a lateral electric field  
between said auxiliary electrode and said conductor  
pattern; and an opposing electrode formed on said  
35   second substrate;

          said method comprising the step of:  
applying to said auxiliary electrode a



1 common voltage substantially equal to a central  
voltage of said alternate-current driving voltage  
signal.

Other objects and further features of the  
5 present invention will become apparent from the  
following detailed description when read in  
conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

10 FIG.1 is a diagram showing the construction  
of a liquid crystal display panel of a related art in  
a plan view;

FIG.2 is a diagram showing the construction  
of the liquid crystal display device of FIG.1 in a  
15 cross-sectional view;

FIG.3 is a diagram showing the waveform of a  
driving signal used in the liquid crystal display  
device of FIGS.1 and 2;

FIGS.4A and 4B are diagrams showing the  
20 electric flux line and the alignment of the liquid  
crystal molecules in a liquid crystal layer used in  
the liquid crystal display panel of FIGS.1 and 2;

FIG.5 is a diagram showing the construction  
of a liquid crystal display device according to a  
25 first embodiment of the present invention in a block  
diagram;

FIGS.6A and 6B are diagrams showing the  
electric flux line and the alignment of the liquid  
crystal molecules in a liquid crystal layer used in  
30 the liquid crystal display panel of FIG.5;

FIG.7 is a diagram showing the possible  
range of an optimum common voltage according to the  
first embodiment of the present invention;

FIG.8 is a diagram showing the waveform of  
35 another driving voltage signal according to a second  
embodiment of the present invention; and

FIG.9 is a diagram showing the optimum

1 common voltage corresponding to the driving voltage  
signal of FIG.8 according to the second embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 [FIRST EMBODIMENT]

FIG.5 shows the construction of a liquid  
crystal display device 20 according to a first  
embodiment of the present invention, wherein those  
parts corresponding to the parts described previously  
10 are designated by the same reference numerals and the  
description thereof will be omitted.

Referring to FIG.5, the liquid crystal  
display device 20 includes, in addition to the liquid  
crystal panel 10 described previously with reference  
15 to FIGS.1 and 2, a scanning-electrode driving circuit  
21 for selectively activating the gate bus lines  $G_1 - G_n$   
and a signal electrode driving circuit 22 for  
supplying the A.C. driving signal explained with  
reference to FIG.3 to the data bus lines  $D_1 - D_m$ , and  
20 there is further provided a D.C. voltage source 23  
supplying the common voltage  $V_{CS}$  to the opposing  
electrode 15 and to the auxiliary electrode Cs as a  
common voltage supply source. FIG.5 further indicates  
a capacitor PIXEL, wherein it should be noted that the  
25 capacitor PIXEL represents the capacitance formed  
between the transparent pixel electrode  $P_1$  or  $P_2$  and  
the transparent opposing electrode 15.

The liquid crystal display device 20 of  
FIG.5 is a so-called low-voltage liquid crystal  
30 display device and the signal electrode driving  
circuit supplies a bipolar driving voltage pulse  
signal similar to the one shown in FIG.3 to the data  
bus lines  $D_1 - D_m$  with an amplitude of  $\pm 5V$ .

In the present invention, the inventor has  
35 discovered that the formation of the disclination  
becomes substantially the same in the state in which a  
driving voltage pulse of  $+5V$  is applied to the

1 selected data bus line  $D_1 - D_m$  and in the state in  
which a driving voltage pulse of -5V is applied to the  
selected data bus line  $D_1 - D_m$ , by setting the common  
voltage  $V_{CS}$  supplied from the common voltage source  
5 23, to be equal to the central voltage (0V) of the  
bipolar driving voltage pulse signal. As a result,  
although the leakage of the light itself is not  
eliminated, the flicker of the leakage light is  
successfully eliminated. Further, it was discovered  
10 that, by setting the voltage  $V_{CS}$  as set forth above,  
the sticking of images caused as a result of the flow  
of the liquid crystal molecules in the liquid crystal  
layer 11C, is also suppressed successfully.

FIGS.6A and 6B show the electric flux in the  
15 liquid crystal layer 10C for the case in which the  
common voltage  $V_{CS}$  is set to 0 V.

Referring to FIGS.6A and 6B, it can be seen  
that, although the disclination formation in the  
liquid crystal layer 10C by the lateral electric field  
20 is not avoidable, the degree of the disclination in  
the liquid crystal layer 10C is more or the same in  
the state of FIG.6A in which a driving voltage pulse  
of +5V is applied to the selected signal electrode  $D_1$   
-  $D_m$  and in the state of FIG.6B in which a driving  
25 voltage pulse of -5V is applied to the selected signal  
electrode  $D_1 - D_m$ . As a result, there occurs no  
substantial flicker in the light that has leaked  
through the liquid crystal display device.

Further, as a result of the reduced  
30 disclination formation in the liquid crystal layer 10C  
caused by the foregoing setting of the common voltage  
 $V_{CS}$ , the flow of the liquid crystal molecules is also  
reduced. As a result, the problem of thickness  
increase in the liquid crystal layer 10C and  
35 associated problem of local accumulation of the  
impurity ions in the liquid crystal layer 10C are  
effectively reduced. Thus, the present invention

1 reduces the sticking of images in the liquid crystal  
display device 20 of FIG.5 by setting the common  
voltage  $V_{CS}$  to be equal to 0V.

FIG.7 shows the flicker formation in the  
5 liquid crystal panel 10 having a 12-inch diagonal size  
for the case in which the common voltage  $V_{CS}$  is  
changed variously, wherein FIG.7 represents the  
flicker formation represented in terms of a domain  
fluctuation DF defined as

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$$DF = (B_p - B_n)/B_p \times 100 \quad (B_p > B_n),$$

where  $B_p$  represents the leakage of light during the  
positive frame interval in which a positive drive  
15 voltage pulse of +5V is applied, while  $B_n$  represents  
the leakage of light during the negative frame  
interval in which a negative drive voltage pulse of  
-5V is applied. Further, FIG.7 represents the  
thickness increase observed for the liquid crystal  
20 layer 10C of the liquid crystal display device 20 of  
FIG.5, wherein the thickness increase was measured at  
a point offset from the right upper corner of the 12-  
inch panel 10 by a distance of 2cm in the lateral  
direction and 2cm in the longitudinal direction. The  
25 measurement was made after 20 minutes of operation.

Referring to FIG.7, it can be seen that the  
domain fluctuation, and hence the flicker formation,  
increases with increasing deviation of the common  
voltage  $V_{CS}$  from the central voltage of the bipolar  
30 driving voltage pulse. Further, it can be seen that  
there appears a liquid crystal flow in the panel  
diagonal direction along the rubbing direction of the  
molecular alignment film 14, wherein the liquid  
crystal flow appears particularly conspicuously in the  
35 black representation mode in which the amplitude of  
the driving voltage pulse signal applied to the liquid  
crystal panel 10 becomes maximum. As a result, the

1 cell thickness of the liquid crystal layer 10C is also  
increased. As explained already, such an increase in  
the liquid crystal cell thickness tends to invite an  
accumulation of impurity ions contained in the liquid  
5 crystal, and the contamination of the liquid crystal  
by such an accumulation of the impurity ions induces a  
conspicuous sticking in the represented images.

In FIG.7, it can be seen that, in a region A  
in which the deviation  $\Delta C$  of the common voltage  $V_{CS}$  is  
10 less than about 0.025V, in other words in the region A  
in which the foregoing deviation  $\Delta V_C$  is less than about  
1/20 of the voltage amplitude (5V) of the drive  
voltage pulse, the domain fluctuation DF is less than  
about 10% and no substantial sticking of images is  
15 recognized. On the contrary, in a region B in which  
the foregoing deviation  $\Delta V_C$  exceeds 0.25V but is  
smaller than about 2V, a linear sticking was  
recognized. Further, in a region C in which the  
deviation  $\Delta V_C$  exceeds about 2V, the domain fluctuation  
20 exceeds 50% and a considerable flicker is recognized.  
Further, the thickness increase of the liquid crystal  
layer 10C reaches as much as 0.025  $\mu\text{m}$ . In this case,  
the liquid crystal molecules are caused to flow in the  
liquid crystal layer 10C with a velocity such that the  
25 liquid crystal molecules move by a distance of more  
than 80  $\mu\text{m}$  during the interval of 24 hours.

From the foregoing, it is preferable to set  
the common voltage  $V_{CS}$  in the region B in which the  
deviation  $\Delta V_C$  with respect to the amplitude center of  
30 the bipolar driving pulse voltage signal is less than  
about 50% of the maximum voltage amplitude for the  
black representation mode, more preferably in the  
region A in which the deviation  $\Delta V_C$  is less than about  
10%. In the region B, it should be noted that the  
35 liquid crystal molecules in the liquid crystal layer  
10C moves over a distance of 80  $\mu\text{m}$  or less during the  
interval of 24 hours.

1           It should be noted that the foregoing result  
is not only pertinent to the liquid crystal panel of  
the 12-inch size but is applicable also to general  
liquid crystal panels having a diagonal size of 10 -  
5   13 inches.

[SECOND EMBODIMENT]

          In the foregoing embodiment, it was assumed  
that the drive voltage pulse signal supplied to the  
10   data bus lines  $D_1 - D_m$  is a bipolar voltage pulse  
having a central voltage of 0V. The present  
invention, however, is never limited to such a  
particular driving signal but is applicable to the  
case in which the driving voltage pulse signal  
15   includes a D.C. voltage offset as represented in  
FIG.8.

          Referring to FIG.8, the driving voltage  
pulse signal has a voltage amplitude of  $\pm 2.5V$  in the  
black representation mode, and the driving voltage  
20   pulse signal is supplied to the data bus line  $D_1 - D_m$   
together with a D.C. offset of 2.37V. Thereby, an  
optimum common voltage  $V_{CS}$  of 2.37V, which is  
substantially equal to the foregoing D.C. voltage  
offset, is applied to the auxiliary electrode Cs and  
25   to the opposing electrode 15.

          In the driving process noted above, it  
should be noted that the optimum common voltage  $V_{CS}$   
may be different in the black representation mode and  
in the white representation mode. In the example of  
30   FIG.8, the common voltage  $V_{CS}$  optimized for the case  
in which the amplitude of the driving voltage pulse  
signal is set smaller than the threshold voltage of  
image representation, does not coincide with the  
common voltage  $V_{CS}$  of 2.37 V optimized for the black  
35   representation mode. In fact, the optimized common  
voltage for the foregoing case takes a value of 2.42V  
rather than 2.37V. FIG.9 represents the relationship

1       between the optimum common voltage  $V_{CS}$  and the  
gradation level for two different liquid crystal  
panels A and B.

5       In view of the fact that the common voltage  
 $V_{CS}$  is applied to the entirety of the liquid crystal  
panel, it is difficult to change the optimum common  
voltage  $V_{CS}$  adaptively depending on the gradation  
level to be represented. In the present invention,  
therefore, the optimum common voltage  $V_{CS}$  is optimized  
10      for the black representation mode in which the flow of  
the liquid crystal molecules in the liquid crystal  
layer 10C appears most significantly.

15      In the description heretofore, the present  
invention is described with reference to the so-called  
H-type Cs liquid crystal panel represented in FIGS.1  
and 2. However, the present invention is by no means  
limited to such a specific construction of the liquid  
crystal panel but is applicable to other liquid  
crystal panels such as "independent Cs type" or  
20      "Cs-on-gate type."

25      Further, the present invention is not  
limited to the embodiments described heretofore, but  
various variations and modifications may be made  
without departing from the scope of the invention.

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